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The Contribution of Information and Communication Technologies to Growth in Europe and the US: A Macroeconomic Analysis

by

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*The views expressed in this paper are those of the author and should not be attributed to the European Commission.
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Abstract:
This paper compares the technological and economic developments related to information and communication technologies in the 90s both in the US and Europe. In the first part, comparable information on the impact of ICT production and investment in both economies over the 90s is presented. The empirical evidence suggests that the US has benefited both from ICT production and from investment, while in the case of Europe the effects are so far largely confined to investment. The second part of the paper extends the growth accounting exercise by allowing for various macroeconomic feedback mechanisms and international spillovers. Consistency with the growth accounting analysis is preserved by using a two-country-two-sector-two-skills neoclassical growth model. By allowing for differences in capital adjustment costs and labour markets between Europe and the US the model is used to assess the relative importance of technological and structural factors for explaining the growth gap between the US and Europe. Though both capital adjustment costs and wage rigidity lead to welfare losses in Europe, the paper finds that they cannot explain the growth differential over the last five years. The best explanation seems to be differences in the rate of technical progress in ICT production. Therefore, rather than blaming "Eurosclerosis" in general one should instead focus more narrowly on determinants of comparative advantage, which the US may enjoy in the production of high tech goods.

Introduction

During the 90s we have witnessed a change in the relative growth performance between Europe and the US. While in previous decades Europe managed to have higher growth per capita and higher productivity growth, a pattern that can be regarded as normal given the higher level of income per capita in the US, in the 90s the US economy experienced a remarkable acceleration of productivity growth which could not be matched by the European economy. Growth in the second half of the 90s has returned to levels prevailing on average before the 1973 break. Also TFP growth has accelerated and returned to rates known from the 60's. One possible explanation for the US experience is the rise of a "new economy" in the US. In fact, one outstanding structural development that can be observed in the US economy in recent years is the rising share of ICT capital. For example, Jorgenson and Stiroh (2000) report growth rates of computer capital of 18% p. a. over the period 1990-95 and 34% p. a. for 1995-98, while other capital has only grown by 1.8% and 2.9% respectively. ICT investment rates in Europe have been less strong. While in the US the nominal ICT investment to GDP ratio has almost doubled, it only increased slightly in Europe. Unfortunately a direct comparison between Europe and the US is difficult because, data availability and quality is inferior in Europe. Various attempts have been made so far to look at the impact of ICT in Europe. Schreyer (2000) and Daveri (2000) have analysed the growth impact of ICT investment on growth within a growth accounting framework. Van Ark (2000) looks at investment and production, however, he uses a methodology which is not directly comparable to existing US studies. All these studies conclude that there is a growth contribution from ICT investment, however, the effect is smaller than in the US. This paper complements previous research for Europe by providing comparable cross country information for the US and Europe on investment and production, using an alternative data source. Based on this evidence the paper explores the role of technology and institutional differences between Europe and the US for explaining recent macroeconomic trends.

There are basically four channels through which ICT can have an effect on macro economic growth. The first is the investment channel itself, namely the increase in productive potential due to the accumulation of ICT capital. This can take the form of increased output of existing goods and services but it can also mean the provision of new products and services. The second channel is the rapid technical progress, currently occurring in the production of ICT goods itself. The third channel consists of possible production externalities (either embodiment effects or economy-wide network externalities) which may be associated with the ICT investment. Finally, the increase in demand for information technology may spur demand for other forms of capital and labour as well. However, to the extent in which ICT capital replaces other inputs and the restructuring leads to frictions in capital and labour markets, the fourth channel could potentially also have some negative effects on growth, at least in the short and medium run. Consequently, the macroeconomic effects of ICT on growth could be smaller than predicted by a pure growth accounting exercise. Some recent research in fact indicates that adjustment costs may be important (see, for example, Hornstein, Krusell (1996) and Kiley (1999)). Therefore, at least initially, institutional differences between the two economies could have a strong impact on how the ICT technology shock was transmitted in both economies. The current technological revolution, which is associated with a rapid fall of investment goods prices (see Greenwood, Hercowitz and Krusell (1997) or Gordon (1990)) poses a special risk for low skilled workers, because the bulk of empirical evidence points in the direction of high substitutability of low skilled workers with capital (see, for example Krusell et al. (2000)). The functioning of labour markets may therefore be crucial for the transmission of the technology shock. A flexible labour market could substantially speed up the reallocation of labour to other uses, while labour market rigidities could mitigate the growth effects from ICT.

There is a widespread belief that both capital and labour markets are more flexible in the US than in the EU and it is therefore often argued that market rigidities in Europe are a crucial factor for explaining the growth differential between the US and the EU in the 90s (see, for example Visco et al. (1999)). The current paper therefore tries to decompose the growth differential between Europe and the US into contributions coming from cross country differences in the size of the technology shock itself and contributions coming from capital adjustment and labour markets. Obviously such a "decomposition" must go beyond pure growth accounting and requires a more structural economic analysis where investment behaviour and labour markets must explicitly be specified. A more structural approach is also required because strong trade and financial linkages between Europe and the US are likely to lead to substantial international spillover effects. The growth effects are analysed with a "two-country-two-sector-two-skills" variant of the conventional neoclassical growth model, calibrated for the EU and the US. In order to analyse and quantify the role of market rigidities, the model allows for capital adjustment costs and labour market imperfections.

The paper is organised as follows: The first section presents an empirical assessment of the role played by the new economy in Europe and the US and discusses the first three channels outlined above. The framework used for this exercise is growth accounting which in this analysis serves the useful purpose of providing information about the technology and the size and sectoral location of the technology shock. Given the limited data availability in Europe certain assumptions must be made in order to carry out such an analysis. The first section explains the methodology. The second section presents results for EU countries and the US and discusses their plausibility in the light of other available information. The results in this section allow us to determine the size of the technology shock which is a crucial input for the model analysis, carried out in the second part of the paper. Additional empirical evidence is used in order to identify differences in the degree of market rigidity in both countries. On the basis of these estimates, the growth effects of a TFP shock are presented and a decomposition into technological factors, international spillovers and institutional rigidities is conducted.

Part I: Empirical Evidence on ICT in Europe and the US

This section presents empirical evidence on the magnitude of the growth effects which can be expected from the first three channels. A suitable tool for such an analysis is growth accounting which has also been extensively applied for US data (see Oliner and Sichel(2000), Oliner (1996) Jorgenson and Stiroh (2000) Whelan(1999)). First we analyse the growth effects of ICT investment, taking as given the growth rate of TFP. In a second step we look at how much technical progress in ICT production has contributed to aggregate TFP and finally we assess the impact of ICT investment on TFP growth.

ICT Investment and Growth (Channel 1)

Using a production theoretic framework is useful since it allows to look at the growth impact of ICT capital (K^I) by taking into account the productive contribution of other relevant inputs such as labour (L) and other forms of capital (K^O). Moreover such a framework also provides information on advances in productivity which cannot be attributed to specific inputs, also known as total factor productivity (TFP).Using a standard neoclassical production function, total output can be represented as

(1) $$Y = F(L, K^I, K^O)TFP\ .$$

One can express eq. (1) in growth rates as follows

$$(2) \qquad g^{Y} = \frac{\partial Y}{\partial K^{O}} \frac{K^{O}}{Y} g^{O} + \frac{\partial Y}{\partial K^{I}} \frac{K^{I}}{Y} g^{I} + \frac{\partial Y}{\partial L} \frac{L}{Y} g^{L} + g^{TFP} .$$

This expression shows that the growth rate of output (g^{Y}) can be represented as a weighted average of the growth rates of traditional capital (g^{O}), ICT capital (g^{I}) and labour (g^{L}) where the weights are given by the respective marginal product of the input multiplied with the factor input to output ratio. Finally the growth rate of technical progress (g^{TFP})has a coefficient of one. Under the assumption of constant returns to scale and perfect competition[1] the (unobservable) marginal product of an individual input can be equated with its factor price, which in principle can be observed. In the case of ICT capital, the following relationship between the marginal product of ICT capital and capital costs is implied by the first order conditions of cost minimisation

$$(3) \qquad \frac{\partial Y}{\partial K^{I}} = cc = (r - (\pi - \pi^{I}) + \delta^{I}) \frac{p^{I}}{p} .$$

Capital cost consist of an internal rate of return (r), the price of ICT investment goods (p), relative to the GDP deflator (*p*), the rate of price decline of investment goods (π^{I}), relative to GDP (π) and the depreciation rate. Substituting factor prices for marginal products in (2) then yields the decomposition of output growth where the inputs are weighed by their respective factor shares

$$(4) \qquad g^{Y} = s_{O} g^{O} + s_{I} g^{I} + s_{L} g^{L} + g^{TFP}$$

Using equation (4) the elasticity of output with respect to ICT capital is simply given by the nominal revenue share of ICT capital and consequently the contribution of ICT capital to the growth of output is given by $s_{I} g^{I}$. Unfortunately information on real ICT capital stocks are not provided by EU statistical offices and the information on ICT investment goods prices suffers from inadequate treatment of quality change. The only statistical information that is available are nominal ICT investment shares.

However, using this information it is nevertheless possible to empirically assess the growth contribution of ICT capital, conditional on estimates of the evolution of relative ICT prices, the depreciation rate and the initial capital stock or alternatively, the elasticity of substitution between ICT and non-ICT factors of production. Here, the assumptions entering the estimates are discussed. A comparison between EU and US ICT deflators show large discrepancies. Unfortunately international comparison is difficult since statistical offices use very different methods to deal with the problem of quality change which occurs especially rapidly in the case of ICT products. In the case of computers, the quality changes between one generation and another is made up of changes in speed, memory, size of hard-disk, speed of CD-ROM, presence of software etc. As long as product characteristics can be quantified hedonic deflators seem to be the most appropriate and transparent method and the US statistical office has switched to the hedonic method for a wide range of high tech products. This method defines the unit price of each characteristic entering the product via econometric estimation. Given these estimated unit prices more adequate volume measures can be computed. The volume measure is basically a weighted average of physical characteristics with unit prices of characteristics

[1] Since in the case of imperfect competition, factors of productiojn are paid less than their marginal product, this method underestimates the growth contribution of inputs by the reciprocal of the mark up ratio.

as weights. So far only France and Sweden apply this method on a very restricted and experimental basis for calculating computer price indices.

Other European statistical offices are still using more traditional ways of dealing with quality changes, namely the “option price method” or the “overlapping method” (or purely judgmental approaches). Consequently computer deflators report very different rates of price decline in Europe. France, which uses hedonic measures reports a price decline of 80% over the 90s, while Germany, which uses the overlapping method only reports price declines of 20% and the UK, which uses judgmental methods and the option price method reports price declines of 40%. In the US hedonic methods are not only applied to computer hardware but also partly to communications equipment[2]. Therefore we use an ICT deflator for the US as a benchmark for the rate of price decline of ICT equipment. It has become a common practice to use relative US price ratios as proxies for relative prices in EU countries and discard the price information provided by national sources (see for example Bundesbank (2000)). Using the US information seems plausible given the characteristics of ICT goods and the information of similar price declines for computers, reported in EU countries which use hedonic methods as well. Nevertheless some caution seems necessary. Assuming similar relative ICT investment prices implies similar relative productivity developments between ICT and non-ICT goods in Europe and the US. This seems hard to reconcile with sectoral productivity developments (see discussion of channel 2). Also, identical relative price developments would imply a similar composition of investment (both ICT and non ICT) in the US and the EU. Given these uncertainties, results will be reported both under the assumption of identical relative price changes for the US and EU countries as well as under the alternative that Europe only experienced 50% of the acceleration of price reductions in the US between the first and the second half of the 90s.

In any growth accounting exercise, estimates of capital costs are crucial because of their role as indicators of marginal product. Besides investment goods prices, information on the rate of depreciation as well as the internal rate of return or the required rate of interest of capital owners is required. For depreciation we adopt the US estimates of around 30%. The internal rate of return is approximated by the average real interest rate across all countries in the sample. It can of course be argued that the internal rate of return differs between the EU and the US because of different modes of financing. For example, the internal rate of return could be lower in the US, because of a higher share of equity financing and lower risk premia required by financing institutions. On the other hand average stock returns seem to be higher in the US than in the EU, which would require an adjustment of rates of return in the opposite direction. Notice, however, errors on the internal rate of return are negligible, because ICT capital costs are dominated by ICT price movements and depreciation.

Furthermore, information about the growth rate of real ICT capital is needed. Given the lack of ICT capital stock data, two alternative routes can be chosen. First, one can make assumptions on an initial capital stock. This is a reasonable strategy if long investment series are available, since the measurement error on initial capital diminishes over time with depreciation. However, for most EU countries long ICT investment series do not exist, therefore it must be expected that the initial error will substantially influence the evolution of the capital stock over the relevant period. Our strategy therefore was to use the elasticity of substitution implied by existing studies to estimate the growth rate of the ICT capital stock by assuming a CES approximation to the true technology. Both the Oliner and Sichel and the Schreyer study suggest an elasticity of substitution larger than one for ICT goods while the results reported by Jorgenson and Stiroh are more consistent with an elasticity of substitution of about one. For the results reported below these values were chosen as upper and lower bounds for the price elasticity. Using a CES specification, the growth of ICT capital is given by

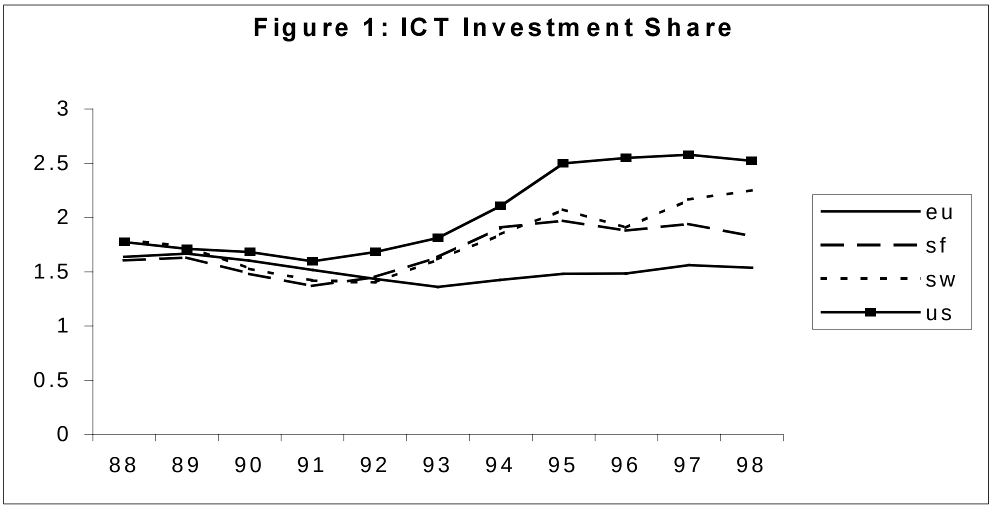
[2] Switching equipment is deflated using hedonic methods while conventional deflators are used for transmission gear such as cables, for example.

(5) $$g^{I} = g^{Y} - \sigma g^{cc}$$

where σ is the elasticity of substitution of ICT capital. Furthermore, using the ICT capital accumulation equation allows us to calculate the ICT contribution to output growth as follows

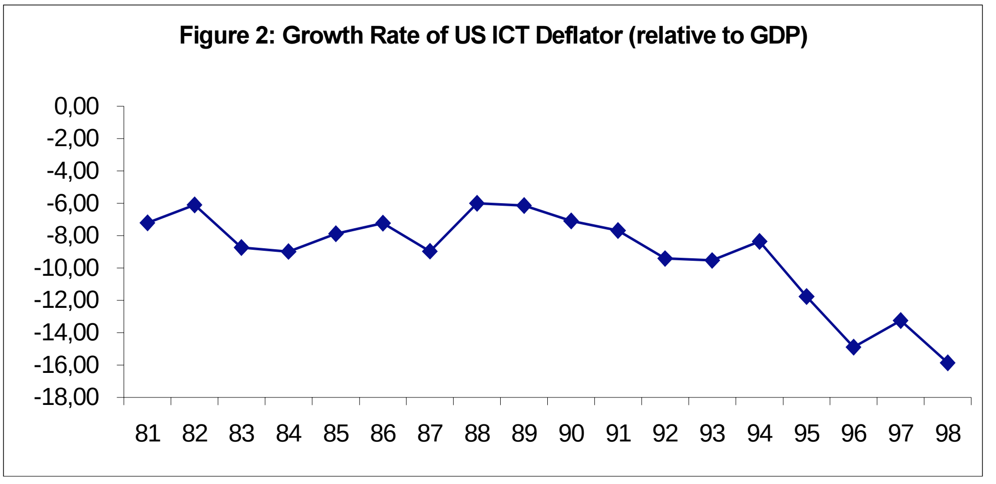
(6) $$\frac{\partial Y}{\partial K^{I}} \frac{K^{I}}{Y} g^{I} = (r - (\pi - \pi^{I}) + \delta^{I}) s^{I} \frac{g^{I}}{g^{I} + \delta^{I}}$$

In order to be consistent with US studies we are looking at a relatively narrow ICT aggregate which consists of computer hardware, semiconductors and telecom equipment. For these categories there exists relatively precise information on prices and TFP growth from US studies (see Oliner and Sichel). Unfortunately, data availability excludes software for EU countries. The individual categories are defined as follows hardware: computer systems, peripherals and office equipment (photocopiers, electronic calculators, electronic cash registers etc.). Telecom equipment: includes facsimile machines, switching and transmission equipment, telephone, videophones, answering machines, accessoirs & parts. Not included in telecom in our definition is radio communication equipment and public broadcasting. From total electronic components we only look at semiconductors, which constitutes a relatively small part of all components. Also not included is consumer video equipment and consumer audio equipment. The following figure provides the basic time series evidence about ICT investment shares in the EU and the US.



Source: REEDS. Aggregate includes: Hardware, Telecom equipment, Semiconductors

Given our discussion of ICT price measurement we use an ICT deflator for the US as a benchmark for the rate of price decline of ICT equipment. The evolution of this deflator (relative to the GDP deflator) is provided in the following table. The figure clearly shows the acceleration in the rate of price decline in the mid 90s.



Source: Jorgenson and Stiroh (2000), own calculations

Table 1.1[3] gives results on the growth contribution of ICT capital under two different assumptions for the elasticity of substitution between ICT and other factors of production. The first two columns give the growth contribution under the assumption of an elasticity (σ) equal to 1.5 which is roughly consistent with the evolution of the ICT income share reported by Schreyer (2000)[4]. The results reported by Oliner and Sichel also suggest an estimate larger than 1. The estimates reported by Jorgenson and Stiroh would however suggest an elasticity of around 1. Column (II) gives the growth contribution under the assumption that EU productivity acceleration was only 50% of the US rate. Figure 1 shows a significant increase of the ICT investment share only for a few EU countries besides the US. This suggests that the price elasticity of EU ICT investment may be lower than in the US. Column (IV) therefore presents results under the assumption that the elasticity of substitution in the EU is only 1. Because of the strong fall of ICT investment prices after 94, we report results separate for the early and late 90s.

[3] Notice, the ICT contribution to output growth in the US is smaller in these figures than in the figures published by OS and JS. The reason is the following: The two papers also include software capital. Also OS use a narrower GDP concept. However, similar to OS and JS these figures also indicate that the ICT contribution has doubled between the first and the second half of the 90s.

[4] It must be borne in mind that Schreyer's calculations of the capital income share are based on assumptions on the initial ICT capital stock. The reported evolution of the income share could simply be an artefact of a particular assumption.

Table 1.1 ICT Contribution to Growth in the 90s
(percentage points)

	(I)		*(II)*		*(III)*		*(IV)*	
	92-94	*95-99*	*92-94*	*95-99*	*92-94*	*95-99*	*92-94*	*95-99*
eu	0,3	0,6	0,3	0,5	0,3	0,4	0,2	0,3
os	0,3	0,5	0,2	0,4	0,2	0,3	0,2	0,3
be	0,4	0,7	0,4	0,6	0,4	0,5	0,3	0,4
dk	0,3	0,5	0,2	0,4	0,2	0,3	0,2	0,3
sf	0,4	0,8	0,3	0,6	0,3	0,5	0,2	0,4
fr	0,3	0,5	0,2	0,4	0,2	0,4	0,2	0,3
de	0,3	0,5	0,3	0,4	0,3	0,3	0,2	0,3
gr	0,2	0,3	0,1	0,2	0,1	0,2	0,1	0,1
ir	1,0	2,3	0,8	1,9	0,8	1,6	0,7	1,4
it	0,3	0,5	0,2	0,4	0,2	0,4	0,2	0,3
nl	0,5	0,8	0,4	0,7	0,4	0,6	0,3	0,5
po	0,3	0,7	0,3	0,6	0,3	0,5	0,2	0,4
es	0,2	0,5	0,2	0,4	0,2	0,3	0,1	0,3
sw	0,4	0,8	0,3	0,7	0,3	0,6	0,2	0,5
uk	0,4	0,8	0,3	0,6	0,3	0,5	0,3	0,4
no	0,3	0,6	0,3	0,5	0,3	0,4	0,2	0,3
ch	0,4	0,7	0,3	0,6	0,3	0,5	0,2	0,4
us	0,5	1,0	0,4	0,9	0,4	0,9	0,3	0,7

(!):pc=ptele, EU=US,sig=1.5
(II):pc n.e. ptele, pcshare:.75,EU=US,sig=1.5
(III):pc n.e. ptele, pcshare:.75,EU=.5*US,sig=1.5
(IV):pc n. e. ptele, pcshare: .75/.8; EU=.5*US,sig=1

As indicated by Table 1.1, like in the US the ICT contribution to growth is rising as well in the EU, though most EU countries are lagging behind the US. Some EU countries (not surprisingly those) with large investment shares also show growth contributions similar to the US. Ireland is a particular case. The growth contribution of ICT for the Irish economy by far exceeds that in the US.

The natural question to ask is: why have investment prices for ICT goods fallen so rapidly in recent years. The obvious answer to this question is high speeds of technical progress in the production of these goods. Recent US studies indicate that a substantial productivity gain comes from an increase in productivity in the ICT producing sector itself.

Technical Progress in the Production of ICT Goods and Services (Channel 2)
It has been shown by Domar (1961) that aggregte TFP can be represented as a weighted average of sectoral TFP with weights represented by the production share of individual sectors in total GDP

$$(7) \qquad TFP = \sum_{i=1}^{N} s_i TFP_i \text{ where } s_i = \frac{production\ value\ of\ \mathrm{sec}tor\ i}{nom.\ GDP}.$$

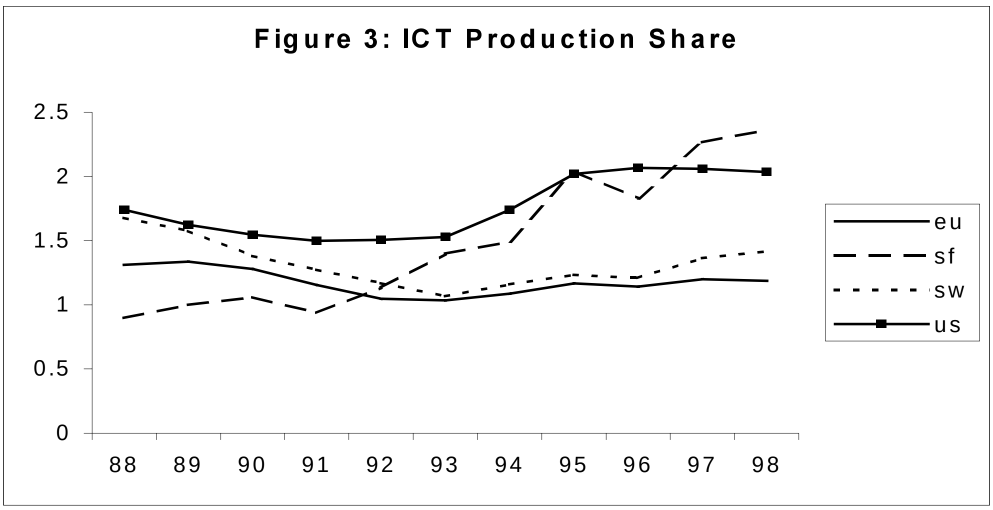
Notice, since the sectoral production values include intermediate inputs the sectoral TFP weights add up to a number exceeding 1. This weighing methodology implies that the sectoral TFP increase is magnified at the aggregate level via the sectoral production linkages. Oliner and Sichel provide the following sectoral decomposition of TFP growth in the US.

Table 1.2: Sectoral decomposition of TFP growth in the US

	74-90	90-95	95-99
Aggregate TFP*	.33	.48	1.16
Contribution from:			
Computer Sector	.12	.16	.26
Semiconductor Sector	.08	.12	.39
Other Nonfarm Business	.13	.20	.50
Growth of TFP:			
Computer Sector	11.2	11.3	16.6
Semiconductor Sector	30.7	22.3	45.0
Other Nonfarm Business	.13	.20	.51

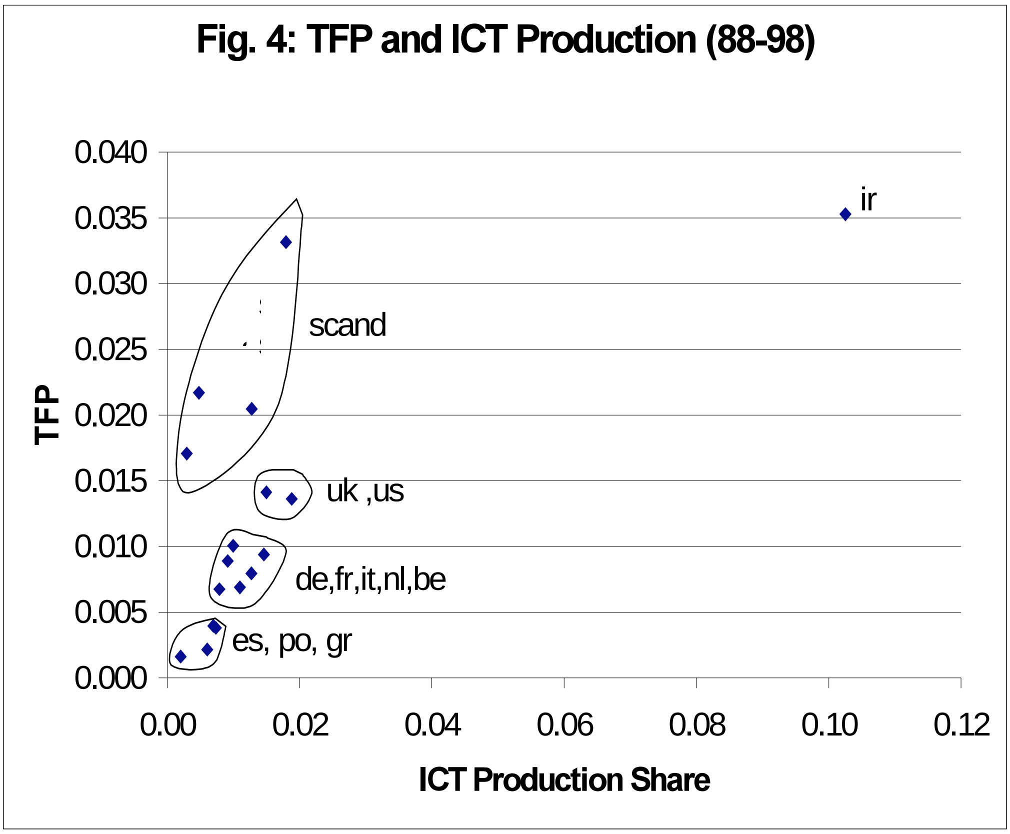
* Nonfarm Business Sector
Source: Oliner and Sichel, Table 4

Results in Table 1.2 show substantially higher rates of technical progress in the computer and semiconductor sector. The figures reported for the US suggest that the computer and the semiconductor sector contribute slightly more than 50% to TFP growth in the US economy, despite its small nominal share in total output. Especially technical progress in the semiconductor industry which is a vital component producing sector for the computer industry has contributed nearly as much to aggregate productivity growth than the rest of nonfarm business in the US. Since little is known about TFP growth in ICT subsectors in Europe we will calculate the contribution of the production sector under two alternative hypothesis. Under the first hypothesis it is assumed that TFP growth accelerated as much in Europe as in the US. Any difference in the aggregate TFP growth in this case must be due to differences in sectoral composition. Alternatively we assumle that TFP growth has accelerated less (by only 50%) in Europe. Given other information, which will be presented below, this seems to be a more reasonable assumption. The following figure provides the basic information on the evolution of ICT production shares in the 90s



Source: REEDS. Aggregate includes: computer hardware, telecommunications equipment and semiconductors

Though there is little direct evidence on the rate of technical progress in ICT production in EU countries, the following figure nevertheless illustrates that there is a positive relationship between the ICT production share and aggregate TFP growth. This indicates that there are higher rates of technical progress in ICT production compared to the rest of the economy.



We use the figures from Table 1.2 on TFP growth as a benchmark. Since no TFP figures are reported for the Telecom sector, make the additional assumption that telecom TFP has increased in the same order of magnitude as in the computer sector. Given the fact that we are looking at a narrow high tech aggregate of the telecom sector this assumption seems justified Table 1.3 shows results from applying these productivity growth rates to the corresponding sectors in Europe and the US.

For the US we arrive at similar growth contribution as obtained by Oliner and Sichel. According to these calculations intertemporal TFP growth differentials are generated by increasing the production share towards ICT goods. Consequently countries like Finland, Sweden and Ireland but also the UK would about double the contribution of the ICT producing sector to aggregate technical progress. The remaining countries would have only managed an increase of around 50%. This difference is entirely due to a composition and a size effect. As can be seen from columns (III) and (IV) of the table, since the nominal ICT production share has not increased very much, the change in the TFP contribution of the sector depends crucially on assumptions about the TFP increase itself. Under the assumption of a 50% acceleration, TFP growth in the ICT sector would only have contributed marginally to overall TFP acceleration.

Table 1.3 Contribution of ICT sectors to aggregate TFP growth

	(I)	*(II)*	*(III)*	*(IV)*
	90-95	95-98	95-98	95-98
eu	0.14	0.24	0.15	0.19
os	0.10	0.18	0.11	0.14
be	0.16	0.22	0.14	0.18
dk	0.04	0.06	0.04	0.05
sf	0.16	0.38	0.25	0.31
fr	0.14	0.25	0.15	0.20
de	0.13	0.19	0.12	0.16
gr	0.02	0.04	0.03	0.03
ir	1.09	2.17	1.41	1.79
it	0.13	0.19	0.12	0.15
nl	0.18	0.27	0.18	0.22
po	0.11	0.22	0.13	0.17
es	0.09	0.14	0.09	0.12
sw	0.15	0.27	0.17	0.22
uk	0.17	0.33	0.21	0.27
no	0.07	0.08	0.05	0.07
ch	0.08	0.14	0.08	0.11
us	0.23	0.50	0.50	0.50

(I): EU-TFP growth=US-TFP growth, ICT Sector

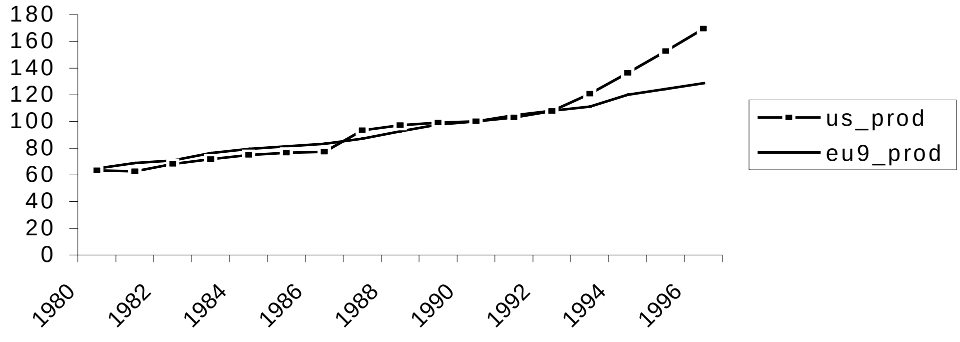
(II): TFP growth acceleration identical in EU and US

(III): No TFP growth acceleration in EU

(IV): TFP growth acceleration EU=50% of US

It must in fact be doubted that technical progress in individual ICT producing sectors was similar at both sides of the Atlantic in the 90s. Productivity figures from high tech manufacturing as published by the OECD[5] suggest that the US actually moved ahead relative to the EU in the 90's.

Figure 5: Labour Productivity in High Tech Manufacturing



[5] OECD Main industrial indicators. High tech manufacturing is defined to include: computers, telecom, biotech and aircraft.

The occurrence of divergence of productivity growth at a sectoral level, especially for tradables is not uncommon among industrialised countries. This has, for example been documented Bernard and Jones (1996) for OECD countries.

The evolution of EU-US bilateral ICT trade in the 90s also supports the view that the US has moved ahead technologically relative to the EU. Though Europe has a permanent deficit in ICT trade with the US, as shown by the following table, import penetration has even increased in the 90s

Table 1.4: Bilateral EU-US Imports as a Share of Total Sales

	1993	1998
EU-Imports from US	18.5	23.4
US-Imports from the EU	6.3	6.1

Source: OECD.

US technological leadership in the ICT sector should also not be too surprising if one looks at research and development effort in the ICT sector in both countries. R&D statistics show a clear pattern of specialisation of US manufacturing in high tech products and here especially computer hardware and its components. The US is concentrating R&D in the high tech sector and in particular in the computer hardware sector, whereas the differences in R&D spending in the medium and low tech sectors are less pronounced between the US and the EU.

Table 1.5: Sectoral R&D Intensity (US, EU9) (% of total output)

	EU		US	
Years:	1980	1995	1980	1995
High tech	9.1	8.3	13.5	12.3
-Office & Computing Machinery	6.2	4.2	12.7	14.7
Medium High tech	1.8	2.6	3.1	4.0
-Machinery & Equipment	1.3	2.0	1.3	2.1
Medium Low tech	0.4	0.6	0.7	0.7
Low tech	0.1	0.2	0.2	0.4

Source OECD

Given the clear links between R&D spending and TFP growth (see, for example Helpman and Coe (1995) for empirical evidence) the recent TFP growth in the US could to a large part be the result of the research effort devoted to the US ICT sector. Recent results by Stern, Porter and Furman (2000) support this view.

Notice also, at this stage of the analysis we take the investment and production shares as given. However the different trends between the EU and the US is itself indicative of a larger productivity effect in the US. In the second part of the paper it will be shown that there exists a link between the ICT investment and production share and the rate of technical innovation in the ICT producing sector.

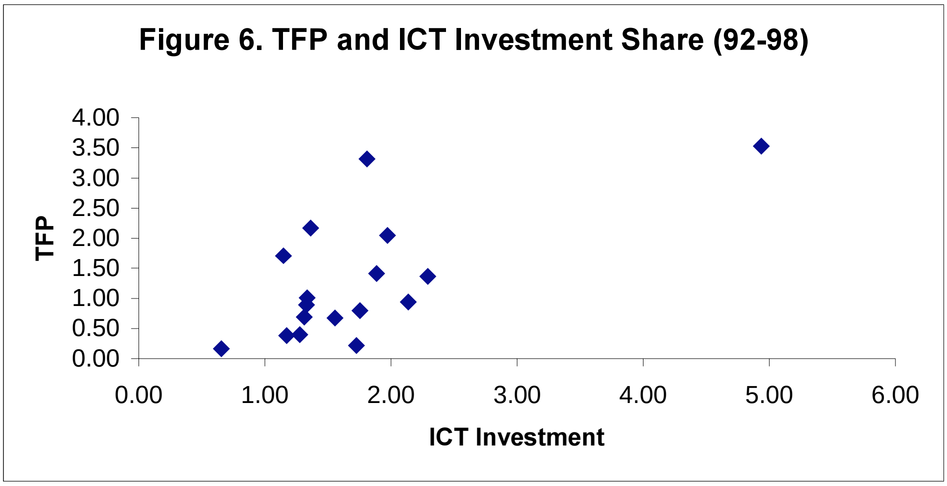
How large are Spillover Effects from using ICT (Channel 3)?

Many new economy advocates see massive cost reductions for firms when they switch to electronic commerce etc. It is unclear what is meant with these statements. Do they refer to cost reductions because ICT capital is getting cheaper and replaces other forms of capital and labour, i. e. do they refer to substitution or the first channel or do they suggest that there might be additional economic gains in the form of embodiment effects or positive spillover effects (network externalities). In this case one should also observe TFP gains in those sectors using ICT capital more intensively or, if the externalities would be economy-wide it could also imply a general increase in the rate of TFP growth. It is this latter effect which we associate with the third channel.

At least at the macroeconomic level there is so far little evidence of significant spillover effects. Even the results for the US do not suggest that TFP has increased strongly in ICT using sectors (other nonfarm business) even if one ignores that the increase in TFP in the remaining 98% of US non farm business from .2% to .5% may be a purely cyclical phenomenon. However, before reaching premature conclusions on this point, it must be noted as Grilliches (1994) observed that more than 70% of private sector US computer investment is concentrated in the service industries such as wholesale and retail trade, finance insurance and real estate and business services, i. e. in sectors where output is not well measured or even the concept of output is not well defined (take for example the output of a business consulting firm). Thus Griliches (1994, page 11) concludes “Why has this [*computer investment*] not translated into visible productivity gains? The major answer to this puzzle is very simple: … This investment has gone into ‘unmeasurable sectors’ and thus its productivity effects which are likely to be quite real, are largely invisible in the data”.

Though measurement constitutes a possible explanation it is hard to tell how serious the problem is. There are various counter-arguments as, for example, put forward by Gordon (1999, 2000) and Triplett (1999). Both Gordon and Triplett argue that though it may appear that the number of new companies and new products associated with ICT is impressive it may not be as impressive when compared to former technological revolutions because of a *base effect* or in other words, because the number of products and services is so much larger now then it was with former technological revolutions it requires many more innovations now per year in order to achieve the same growth rate in productivity. Therefore simply looking at the absolute number of new products and services could be quite misleading. Triplett makes an additional point: Since most of the computer using services are intermediates they do not show up in aggregate statistics. So even if there is a measurement problem only the fraction of services that enters private consumption directly constitutes a problem. Business services do not constitute a problem for aggregate productivity measurement because any error is netted out in the aggregate productivity measure. Take for example the services provided by business consultants. Even though the value added growth rate of consulting services may be biased downwards, but if these services help to increase the production of final output, consulting services should nevertheless show up in aggregate TFP.

If there are important externalities related to ICT investment then one should observe that countries with large ICT investment shares also have large TFP increases. If one simply looks at the correlation between TFP growth and the ICT investment share then it looks as if there exists such a relationship. (see Figure 6). However, the answer is more complicated. The correlation between ICT investment and TFP growth could be spurious if both variables are correlated to a third factor. In this case the third factor could be the ICT production share. In fact the correlation between ICT production and ICT investment across countries is quite large, due to significant domestic production. A further reason why the correlation between ICT investment and aggregate TFP may be spurious are measurement problems in calculating TFP without properly distinguishing between ICT and non-ICT capital. As outlined in the ICT investment section, aggregate capital as constructed from aggregate investment series does not properly weigh the contribution of ICT investment, this measurement error will show up in a positive relationship aggregate TFP and ICT investment.



The following Table presents regression results from a Panel of 16 countries with observations from 1988 to 1998. In order to illustrate the effect of ICT investment on TFP growth under various hypotheses concerning the TFP effect of ICT production.

If one believes that there are large TFP growth differentials between ICT production and the rest of manufacturing and also believes that TFP growth in the ICT sector has accelerated at identical rates both in the US and in the EU (line 1), then the spillover hypothesis can be rejected or taken the estimate at face value, the estimate implies that an increase in the production share of ICT by 1% - which is approximately the difference in the production share between the EU and the US-would increase aggregate TFP growth by .11% points p. a. Even if one assumes that TFP growth accelerated only by 50%, compared to the US (line 2) the ICT investment contribution to technical progress in the total economy does not seem to have been overwhelming. Only if one believes that the TFP growth differentials between the ICT sector and the rest of manufacturing is zero, the contribution of ICT investments could roughly double (line 3).

Table 1.6 The Size of Macroeconomic TFP Spillovers

Hypotheses:	Contribution of a 1% Point Increase of ICT Investment Share to TFP growth (% points)
1) TFP acceleration in the EU like in US	.11 (1.27)
2) TFP acceleration in the EU only 50% of US	.14 (1.54)
3) PROD(Man)=PROD(ICT)	.25 (2.75)

t-Statistics in Parentheses

Part 2: Macroeconomic Implications for Growth and Employment

The analysis so far suggests a strong causal link between productivity gains in the ICT sector and a spread of these productivity improvements throughout the economy via investment in ICT capital. The available evidence also suggests that the acceleration of technical progress was largely concentrated in the US. In this section we look at the macroeconomic repercussions of these technological developments by taking into account possible complementarities and substitution effects both within countries and across countries. The macroeconomic effects of a technology shock can be very different from the initial impulse, depending on how other factors of production adjust to this technological shock. Also, given the level of trade and financial integration of the US and the EU, international spillovers could be substantial.

It is very likely that the way in which markets operate will significantly affect how technological impulses from the ICT sector get transmitted throughout the economy both in terms of magnitudes but also in terms of the sign of these effects. Differences in the functioning of markets is an argument often heard (see, for example, Visco (2000)) in conjunction with explaining the different growth performance of the US and EU economy in the 90s. Therefore, this section will put special emphasis on identifying structural differences between the EU and the US in order to assess the “welfare losses” inflicted by a more rigid market economy in terms of growth and employment.

In order to carry out such an analysis we use a two-country-two-sector-two-skill dynamic general equilibrium model which allows for labour market imperfections and investment adjustment costs[6], which are allowed to differ across countries. It is discussed below how these differences are identified. Otherwise, households in both countries have similar preferences regarding domestic and foreign goods and similar rates of time preferences. Also the technology available to both countries is identical up to difference in the growth rate of technical progress which is taken as exogenous. All goods produced are traded internationally and there is perfect international capital mobility.

Structural Differences between Europe and the US

Capital Adjustment Costs:
The US economy has experienced an investment boom in the 90’s which is unprecedented in post war US economic history. Though the investment to GDP ratio has been rising in Europe as well in recent years, the growth acceleration is far less dramatic than in the US. Of course, differences in investment opportunities because of ICT related innovations is a likely cause for the investment boom. But apart from a purely technological explanation, other more economic explanations could play a role as well. One major structural reason for differences in investment rates in the 90s could be differences in adjustment cost for capital, which may have allowed US companies to take advantage of new technological developments at a more rapid pace compared to their European competitors. Adjustment frictions can take various forms, such as for example government regulations and organisational adjustment and learning frictions within firms. Investment rigidities can also arise in the form of information, transaction and monitoring costs of financial intermediaries (venture capital markets, equity financing). Especially differences in financial markets are often emphasised as being crucial in a EU US comparison. Following Lucas (1967) and Hayashi (1982), in the empirical investment literature adjustment rigidities are generally captured by assuming convex costs of adjustment (see also Chirinko (1995) for a recent survey). Recently, Carlstroem and Fuerst (1999) have shown that financial rigidities can be represented by an adjustment cost specification for investment. The question arises, however, how to quantify these adjustment costs in a simple

[6] See the appendix for a more detailed description of the model and calibration.

macroeconomic indicator and compare their magnitude across countries. From recent business cycle research it is well known that there is a strong link between the magnitude of adjustment costs and the volatility of investment over the cycle (see, for example, Mendoza (1981)). I. e. in an economy without adjustment costs aggregate investment would adjust instantaneously to demand and productivity shocks and one should therefore observe a high volatility of investment. In contrast, if firms face strong costs of adjustment, then investment should be a smoother process. Therefore the standard deviation of investment, relative to GDP can be used in selecting a macroeconomic adjustment cost parameter. The observed investment volatility in the US and Europe is consistent with the view that adjustment costs for capital are smaller in the US, since the standard deviation of the cyclically adjusted investment to GDP ratio is about 20% higher in the US compared to Europe. The respective investment volatility can be matched by the model if one allows adjustment costs to be 13% of total investment expenditure in Europe and 7% in the US (see Roeger (1999)). Imposing the same adjustment cost parameter for different asset types implies asset specific differences in adjustment costs because of differences in depreciation rates. For computer capital, adjustment costs amount to 22% of total investment expenditure in the US and to 40% in the EU. Allowing for larger adjustment costs related to ICT investment is consistent with other research. For example, David (1991) argues that the effect of information technologies on today's economy is comparable to the effects of the dynamo and the subsequent availability of electricity one hundred years ago. Because of learning and organisational adjustments it can take longer with revolutionary new technologies to diffuse in the economy. Hornstein (1999) provides examples of such diffusion processes. Kiley (1999) adopts an extreme position in quantifying ICT related adjustment costs. While traditional growth accounting disregards these costs completely, he argues that adjustment costs for computer capital are quite large. Based on a break-down of IT spending of firms into hardware, training support and software he concludes that only 20 to 40% of total IT spending is hardware and he therefore estimates adjustment costs in a range between 150 to 400% of total IT investment spending. Unfortunately there is little consensus about the magnitude of adjustment costs in general and estimates differ widely. Results from direct estimation often point to very large adjustment costs. Recent estimates presented by Hubbard et al. (1996) suggest that adjustment costs are about 70% of total investment expenditure, however, very imprecisely estimated. Studies which try to match business cycle fluctuations, generally arrive at much lower estimates. The adjustment cost parameter chosen by Mendoza, for example to match investment volatility over the cycle implies that adjustment costs are less than 1% of total investment spending. The figure chosen in this paper lies somewhere in the middle.

Labour Market:
A conclusion common to many studies on the European labour market is that there is a need for increased flexibility, especially when compared to the US labour market. There are at least two dimensions in which EU labour markets differ from those in the US. First, there are differences in hiring and firing costs, due to differences in regulation regarding advance notice and severance pay. This has, for example, been documented by Lazear (1990) or Bentolila and Bertola (1990). Second, there is relatively little wage flexibility across skill groups in EU countries compared to the US. Differences in labour adjustment costs have received substantial attention among economists in the early 90s and were regarded as a potential explanation for differences in unemployment rates. However, both theoretical and empirical research was not very successful in demonstrating that different adjustment costs for labour can explain a substantial part of the difference in unemployment rates. Also the empirical significance of these differences is questioned by the empirical evidence. One should observe significantly higher labour market flows in the US compared to Europe. However, direct evidence on gross labour market flows, as for example presented by Burda and Wyplosz (1994) show rates of job creation and destruction of a similar magnitude both in Europe and the US. Also the relatively high investment rates observed in Europe, do not suggest that labour market institutions do particularly slow down investment activities of firms in Europe. Therefore it

seems difficult to blame hiring and firing rules in Europe for a lack of ICT investment activity in Europe. Therefore in this paper we do not specifically look at the growth implications of differences in labour adjustment costs but concentrate instead on the consequences in differences of wage rigidity across skill groups. Also, this phenomenon has recently attracted more attention as a possible explanation for rising unemployment rates in Europe over the last two decades (see, for example Bertola and Ichino (1995) and Gregg and Manning (1997)). It has often been documented that in contrast to the EU where one observes rising low skilled unemployment, one observes rising skill premia in the US (see Beaudry and Green (2000) for the most recent evidence). These trends could be a direct consequence of differences in the degree of relative wage rigidity between Europe and the US when technical progress is skill biased in favour of high skilled workers. It could therefore be particularly relevant in the ICT context since there exists empirical evidence which suggests that low and high skilled workers are affected differently by ICT investment because of different degrees of substitutability of both types of labour with capital (see, for example, Acemoglu (1998), Autor et al. (1998), Krusell et al (2000)). Relative wage rigidity has implications on how wages and employment of workers - differentiated by skill - are affected by technical progress in the ICT sector. This is also the main focus of the debate. However, there could also be a link running from wage rigidity to growth. If the fall of investment good prices leads to an increase in low skilled unemployment in Europe, while US labour markets manage to provide jobs for low skilled workers, the inefficient use of resources in Europe could have negative growth effects as well. Both, the labour market consequences of relative wage rigidity and its growth implications will be analysed. In this analysis it is assumed that for skilled workers wages are determined in a bargaining framework in both countries. For the US, wages of the low skilled are negotiated independently from high skilled wages, whereas for the EU it is assumed that they are indexed to high skilled wages and wage dispersion is not affected by the unemployment rate of unskilled workers in the EU.

Simulation Experiments

In the following the model will be used to analyse the impact of rapid technological change in the production of ICT goods as identified in the previous section on important macroeconomic variables such as GDP, Consumption, Investment, employment and wages. For this analysis it will be assumed that the higher growth rate of technical progress in ICT production which is visible since the mid 90s will persist over a period of 50 years[7]. Unfortunately the empirical plausibility of the model results can only be checked against a five year sample in the US and the EU. The following table provides the relevant macroeconomic trends observed in both economies over the 90s.

[7] 50 years seems like an arbitrary period. It was chosen largely for technical reasons namely as aperiod long enough to resemble a permanent increase in technical progress and shor enough such that the model can settle on a new steady state given the memory limitations. Sensitivity analysis does however show that the effects over the first 20 years of the simulation are not significantly affected by changes in the period productivity expansion of plus/minus 10 years.

Table 2.1: EU and US in the early and late 90s

	EU15		US	
	Before 94	94-00	Before 94	94-00
GDP*	2.4	2.5	2.9	4.0
Unemployment Rate	8.8	9.8	6.6	4.6
Wage Share	.59	.52	.59	.57
Real Interest Rate	4.8	2.8	3.4	3.9
Investment Share (real)	19.7	20.3	16.7	19.6
ICT-Investment Share**	1.4	1.6	1.8	2.6
ICT-Production Share**	1.0	1.2	1.4	2.1
ICT-Import Share***	18.2	23.1	6.2	6.0

Source: AMECO, REEDS, OECD Bilateral Trade Statistics.
* Average growth rate 81-93
** 1993 and 1998 values
*** Share of US/EU ICT-Imports in total EU/US ICT Sales, 1993 and 1998 values

A clear pattern emerges from this table. In the case of the US on can observe rising growth rates of GDP, an increase in the investment to GDP ratio and rising ICT investment shares. In the US these trends go along with a fall of unemployment, a rise in real interest rates and a real appreciation of the dollar. However, the US manages to increase the share of ICT imports in the EU despite a loss of an exchange rate induced loss of competitiveness. For the EU as a whole, the turnaround of GDP in the late 90s is much more moderate[8]. The same is true for investment and ICT investment and ICT production shares. Finally, EU unemployment was still rising in the second half of the 90s.

TFP Shock in the US and EU ICT sector

The starting point for this experiment is the observed acceleration of TFP growth in the second half of the 90s. Aggregating the subsector information as presented in Table 1.2, the growth rate of TFP has increased by 11% points in the US. Assuming identical growth rates of TFP in the ICT sub-sectors in the EU but taking into account the a different sectoral composition, namely a smaller share of semiconductor production where most of the TFP acceleration took place in the 90, we arrive at a TFP acceleration of 7%. Given the evidence provided in the last section it is doubtful whether productivity growth has actually accelerated at the same speed as in the US, therefore we consider three cases. In the first scenario identical productivity acceleration is assumed while in the second scenario an acceleration of only 50% compared to the US is considered. In a third simulation we assume that there was no acceleration of ICT TFP growth in Europe. This experiment also serves to illustrate the international spillover effects.

A permanent shock to ICT TFP growth of 11% leads to a permanent increase in the growth rate of GDP in the US. The growth rate is .7% points higher after 5 years and about 1% point higher after 15 years. Output growth will stabilise at a level that is about 1% point higher. Sector specific technical progress increases the (nom.) output share of the ICT sector by .46% points after 5 years. This process continues, however, even after 40 years of strong productivity growth, the nominal ICT production share will have increased only by slightly more than 3% points in the US. Also, the ICT investment share increases at a roughly similar rate. Given the fall in ICT investment prices, real

[8] Applying US accounting conventions for the EU implies that GDP growth could have been about .2% higher in the early 90s and about .3% higher in the late 90s in the EU, thus the reported growth differential for the EU between the early and late 90s may be slightly biased downwards.

investment increases steadily. This investment boom is accompanied by higher interest rates. These results for the US are not inconsistent with the observed growth acceleration. The model also matches fairly closely the observed changes of ICT investment and production shares. Higher productivity growth also leads to higher employment of both low and high skilled workers. The positive employment effect occurs mainly because the productivity shock increases the wedge between the reservation wage and labour compensation. Notice, however, differences in the degree of substitutability between low skilled/ high skilled workers and capital implies an increasing skill premium. Both qualitatively and quantitatively these model result seem to be broadly consistent with recent US trends. Provided TFP growth in the US ICT sector continues in the coming years higher growth rates of GDP could be likely.

Table 2.2: Large TFP Shock in EU

	1995	*2000*	*2005*	*2010*	*2020*	*2030*	*2040*
EU:							
TFP-Growth	7.1	7.1	7.1	7.1	7.1	7.1	7.1
GDP_Growth	0.1	0.4	0.6	0.6	0.7	0.8	0.8
Consumption-Growth	-0.1	0.2	0.3	0.5	0.6	0.7	0.8
Computer Price-Inflation	-6.3	-7.2	-7.4	-7.4	-7.4	-7.4	-7.4
Total Employment*	0.0	0.0	-0.1	-0.1	-0.2	-0.3	-0.5
Non-ICT Employment*	-0.1	-0.5	-0.9	-1.3	-1.6	-2.5	-3.4
ICT-Employment*	3.4	18.6	32.1	44.3	56.7	82.7	110.7
High Skilled Employment*	0.0	0.5	1.2	2.1	3.0	5.0	7.2
Low Skilled Employment*	-0.1	-0.8	-1.8	-2.9	-4.1	-6.7	-9.7
Wages (Low Skilled)	0.2	0.4	0.5	0.6	0.6	0.7	0.7
Wages (High Skilled)	0.2	0.4	0.5	0.6	0.6	0.7	0.7
Wage Share	0.0	-0.3	-0.8	-1.3	-2.0	-3.4	-4.9
ICT Investment Share (nom.)	0.1	0.5	0.9	1.3	1.6	2.4	3.2
Investment Share (real)	0.0	1.0	2.4	3.9	5.3	8.4	11.6
ICT Production Share (nom.)	0.1	0.5	0.8	1.1	1.4	2.0	2.7
ICT-Import Share	0.4	1.8	4.0	6.4	8.8	14.0	19.4
Real Exchange Rate	4.8	4.8	4.1	2.8	1.0	-3.9	-10.2
Real Interest Rate	0.1	0.5	0.9	1.2	1.4	1.9	2.3
US:							
TFP-Growth	11.0	11.0	11.0	11.0	11.0	11.0	11.0
GDP_Growth	0.3	0.7	0.9	1.0	1.1	1.1	1.1
Consumption-Growth	0.0	0.2	0.4	0.5	0.5	0.6	0.5
Computer Price-Inflation	-8.7	-10.4	-10.6	-10.6	-10.5	-10.5	-10.5
Total Employment*	0.0	0.4	0.9	1.5	2.1	3.3	4.5
Non-ICT Employment*	0.0	-0.1	0.0	0.3	0.5	0.9	1.2
ICT-Employment*	-1.2	20.0	37.7	53.9	70.6	105.9	144.0
High Skilled Employment*	0.0	0.5	1.2	2.0	2.9	4.6	6.0
Low Skilled Employment*	0.1	0.2	0.5	0.9	1.3	2.0	2.8
Wages (Low Skilled)	0.1	0.4	0.5	0.6	0.6	0.6	0.6
Wages (High Skilled)	0.4	0.7	0.9	1.0	1.0	1.1	1.1
Wage Share	0.0	-0.2	-0.7	-1.2	-1.8	-3.1	-4.4
ICT Investment Share (nom.)	0.0	0.4	0.8	1.0	1.3	2.0	2.7
Investment Share (real)	0.0	1.2	2.8	4.5	6.2	9.6	13.3
ICT Production Share (nom.)	0.0	0.5	0.9	1.2	1.6	2.4	3.3
ICT-Import Share	-1.1	-3.6	-6.6	-9.5	-12.4	-18.0	-23.5
Real Exchange Rate	-4.8	-4.8	-4.1	-2.8	-1.0	3.9	10.2
Real Interest Rate	0.3	0.9	1.4	1.8	2.1	2.7	3.2

Results reported are % point deviations. An asterisk denotes % deviations.

Under the optimistic assumption on European ICT TFP growth, the model predicts an increase in the growth rate of GDP of .38% after the first five years and a further acceleration to .8% after 40 years of noninterupted high TFP growth in the ICT producing sector. The fall of ICT investment prices also generates an investment boom in the EU. In contrast to the US, labour market rigidities in the EU prevent a fall of unemployment because of an increase in low skilled unemployment. In line with the other evidence presented earlier on the magnitude of the technology shock in the European ICT sector this scenario seems too optimistic for the EU, since it implies growth rates of GDP which are not observed in the late 90s. This scenario also overpredicts the rise in the nominal ICT production share in the EU and it seems inconsistent with the rising import share of ICT goods in the EU. Therefore, also the macroeconomic evidence suggests that the technology shock was less strong in the EU. The following table presents results for the EU under the assumption of a significantly smaller ICT technology acceleration.

Table 2.3: Small TFP Shock in EU

	1995	2000	2005	2010	2020	2030	2040
EU:							
TFP-Growth	3.6	3.6	3.6	3.6	3.6	3.6	3.6
GDP_Growth	0.0	0.2	0.3	0.4	0.4	0.5	0.5
Consumption-Growth	0.0	0.1	0.3	0.4	0.5	0.6	0.7
Computer Price-Inflation	-3.5	-4.2	-4.3	-4.4	-4.4	-4.4	-4.4
Total Employment*	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.2
Non-ICT Employment*	0.0	-0.2	-0.3	-0.4	-0.6	-0.8	-1.0
ICT-Employment*	1.2	7.5	11.8	15.1	18.3	25.3	32.9
High Skilled Employment*	-0.1	0.2	0.5	0.9	1.3	2.3	3.5
Low Skilled Employment*	0.0	-0.3	-0.7	-1.1	-1.7	-2.9	-4.4
Wages (Low Skilled)	0.1	0.2	0.3	0.3	0.3	0.4	0.4
Wages (High Skilled)	0.1	0.2	0.3	0.3	0.3	0.4	0.4
Wage Share	0.0	-0.2	-0.5	-0.9	-1.4	-2.4	-3.5
ICT Investment Share (nom.)	0.0	0.3	0.5	0.7	0.9	1.3	1.7
Investment Share (real)	-0.4	0.2	1.0	1.8	2.6	4.3	6.1
ICT Production Share (nom.)	0.0	0.2	0.3	0.4	0.4	0.6	0.8
ICT-Import Share	1.0	4.2	8.7	13.6	18.6	29.4	41.1
Real Exchange Rate	8.5	7.7	5.6	2.6	-1.1	-10.1	-21.0
Real Interest Rate	0.0	0.3	0.6	0.8	1.0	1.3	1.6
US:							
TFP-Growth	11.0	11.0	11.0	11.0	11.0	11.0	11.0
GDP_Growth	0.3	0.7	0.9	1.0	1.1	1.1	1.1
Consumption-Growth	0.0	0.2	0.4	0.5	0.5	0.5	0.4
Computer Price-Inflation	-8.7	-10.3	-10.6	-10.5	-10.5	-10.5	-10.4
Total Employment*	0.0	0.4	1.0	1.6	2.3	3.5	4.7
Non-ICT Employment*	0.0	-0.1	0.0	0.2	0.4	0.8	1.0
ICT-Employment*	-0.9	21.9	41.8	60.4	79.4	119.5	162.3
High Skilled Employment*	0.0	0.6	1.4	2.2	3.2	4.9	6.5
Low Skilled Employment*	0.1	0.2	0.6	0.9	1.3	2.0	2.8
Wages (Low Skilled)	0.2	0.4	0.5	0.6	0.6	0.6	0.6
Wages (High Skilled)	0.5	0.8	0.9	1.0	1.1	1.1	1.1
Wage Share	0.0	-0.3	-0.7	-1.3	-1.9	-3.2	-4.5
ICT Investment Share (nom.)	0.0	0.4	0.8	1.1	1.4	2.0	2.7
Investment Share (real)	0.2	1.4	3.0	4.7	6.4	9.8	13.4
ICT Production Share (nom.)	0.0	0.5	1.0	1.4	1.8	2.7	3.7
ICT-Import Share	-1.7	-6.3	-11.8	-17.2	-22.4	-32.2	-41.4
Real Exchange Rate	-8.5	-7.7	-5.6	-2.6	1.1	10.1	21.0
Real Interest Rate	0.4	0.9	1.4	1.7	2.0	2.5	3.0

With a more modest assumption on ICT TFP growth in Europe, the model replicates surprisingly well the observed change in the ICT production and investment and import share in the EU. This can be regarded as further evidence in favour of lower rates of technical progress in recent years. A technology shock in this order of magnitude would only lead to a slow acceleration of GDP growth in Europe which according to these results would be .2% points higher after 5 years. However this process continues and the growth rate could go up by .5% in the long run. However, this growth appears disproportionate given the small size of the technology shock. According to the simulation results the growth rate in the EU is half the growth rate in the US despite a rate of technical progress in the ICT producing sector which is only a quarter of that in the US. A plausible explanation for this phenomenon are international spillovers. In order to isolate these effects, the following table presents results of a simulation experiment where technical progress is concentrated entirely in the US.

Table 2.4: Pure International Spillover Effect

	1995	2000	2005	2010	2020	2030	2040
EU:							
TFP-Growth	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GDP_Growth	-0.1	0.0	0.0	0.1	0.1	0.2	0.2
Consumption-Growth	0.0	0.1	0.2	0.3	0.4	0.5	0.6
Computer Price-Inflation	-0.8	-1.2	-1.3	-1.3	-1.3	-1.4	-1.5
Total Employment*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-ICT Employment*	0.0	0.1	0.2	0.3	0.4	0.7	0.9
ICT-Employment*	-1.0	-3.4	-7.9	-12.8	-17.8	-27.7	-37.3
High Skilled Employment*	0.0	-0.2	-0.3	-0.4	-0.3	-0.3	-0.2
Low Skilled Employment*	0.1	0.2	0.4	0.5	0.5	0.5	0.4
Wages (Low Skilled)	-0.1	-0.1	0.0	0.0	0.0	0.1	0.1
Wages (High Skilled)	-0.1	-0.1	0.0	0.0	0.0	0.1	0.1
Wage Share	0.0	-0.1	-0.3	-0.5	-0.8	-1.4	-2.2
ICT Investment Share (nom.)	0.0	0.0	0.1	0.1	0.2	0.2	0.3
Investment Share (real)	-0.7	-0.6	-0.4	-0.2	0.0	0.5	1.2
ICT Production Share (nom.)	0.0	-0.1	-0.2	-0.3	-0.5	-0.7	-1.0
ICT-Import Share	1.6	6.6	13.6	21.2	29.1	46.5	65.9
Real Exchange Rate	12.1	10.6	7.1	2.3	-3.3	-16.5	-31.9
Real Interest Rate	-0.1	0.1	0.2	0.4	0.5	0.7	0.9
US:							
TFP-Growth	11.0	11.0	11.0	11.0	11.0	11.0	11.0
GDP_Growth	0.4	0.8	1.0	1.0	1.1	1.1	1.1
Consumption-Growth	0.1	0.2	0.4	0.4	0.4	0.4	0.3
Computer Price-Inflation	-8.7	-10.3	-10.5	-10.5	-10.4	-10.4	-10.4
Total Employment*	0.0	0.5	1.1	1.7	2.4	3.8	5.0
Non-ICT Employment*	0.0	-0.1	0.0	0.2	0.4	0.7	0.8
ICT-Employment*	-0.5	23.7	45.9	66.9	88.2	132.9	180.5
High Skilled Employment*	0.0	0.7	1.6	2.5	3.5	5.3	7.1
Low Skilled Employment*	0.1	0.2	0.6	0.9	1.3	2.1	2.8
Wages (Low Skilled)	0.2	0.4	0.6	0.6	0.6	0.6	0.6
Wages (High Skilled)	0.5	0.8	0.9	1.0	1.1	1.1	1.1
Wage Share	0.0	-0.3	-0.8	-1.4	-2.0	-3.3	-4.6
ICT Investment Share (nom.)	0.0	0.4	0.8	1.1	1.4	2.0	2.7
Investment Share (real)	0.3	1.6	3.2	4.9	6.6	10.0	13.6
ICT Production Share (nom.)	0.0	0.6	1.1	1.5	2.0	3.0	4.1
ICT-Import Share	-2.4	-8.9	-16.9	-24.4	-31.6	-45.0	-56.9
Real Exchange Rate	-12.1	-10.6	-7.1	-2.3	3.3	16.5	31.9
Real Interest Rate	0.4	0.9	1.3	1.7	1.9	2.4	2.8

Though the EU benefits in principle from lower investment goods prices as well, this effect is initially more than compensated from a capital outflow to the US because of higher expected returns. Therefore initially the transmission is negative. This is associated with a depreciation of the Euro. However, the sign of the spillover reverses in the longer term as the US is accumulating a current account deficit because of higher import demand. Of course there are crucial negative sectoral effects. Continuous technical progress in the US combined with a technologically stagnant high tech sector in the EU, wipes out high tech production in the EU. A clear pattern of specialisation emerges with an expanding ICT sector in the US, while the EU is concentrating on non-ICT production. Nevertheless, the aggregate effects of a technology shock in the US are positive for the EU in the long run since the corporate sector as a whole in Europe benefits from lower investment prices as well.

How important are Capital Adjustment and Labour Market Rigidities?

An important policy question is whether Europe could have benefited substantially more from the ICT revolution if it had a more flexible economy. The following experiments try to quantify the importance of capital adjustment costs and relative wage rigidities. We first concentrate on differences in capital adjustment costs. In the following we calculate how the EU economy would respond to a technology shock if capital adjustment costs were actually reduced to US levels. As can be seen from table (), reducing adjustment costs for capital could lead to substantial long term gains. In the long run, the increase in the growth rate induced by the TFP shock could be up to .5% points higher. However, in the short run growth differentials would actually be small and hardly visible in the first 5 years. It seems difficult to explain a sudden acceleration of growth in the neoclassical growth model as an outcome of capital accumulation. Though equipment investment can jump to a higher growth rate immediately after the technology shock is perceived as permanent by investors, this has only a small impact effect on the growth rate of the capital stock. On impact the ratio of the change in the growth rate of capital to the change in the growth rate of investment is given by the historic investment to capital ratio. Thus an increase in the growth rate of investment by 1% point increase the growth rate of capital only by I/K% points on impact. Only after a transition period of more than 10 years will the growth rate of capital approach the growth rate of investment. Thus the growth rate of output, which is determined by the growth rate of the capital stock, and not of investment, will only accelerate slowly and over a long transition period. In other words, even if investment in Europe would have responded more rapidly to a technology shock, this would only have a visible impact on the growth rate of GDP after 5 years but not before. This “investment pessimism” of the standard growth model has a certain empirical backing. Easterly and Levine (2000) report an interesting “stylised fact” on the relationship between labour productivity growth and capital accumulation: labour productivity seems much less persistent than capital accumulation. This is obviously true over the business cycle, but it also seems to hold in the medium term. The last two decades represent a good example for this fact. The US has overtaken the EU in terms of labour productivity growth, but at the same time, the contribution of physical capital to growth has remained remarkably stable in both regions. Productivity growth in the US is higher now than in Europe not because the US has accumulated more capital in recent years but because the US economy has managed to achieve higher rates of TFP growth or technical progress. In other words, sudden accelerations of productivity growth are likely due to technology shocks, rather than to investment booms.

Table 2.5: Lower capital Adjustment Costs in EU

	1995	2000	2005	2010	2020	2030	2040
EU:							
TFP-Growth	3.6	3.6	3.6	3.6	3.6	3.6	3.6
GDP_Growth	-0.1	0.2	0.4	0.5	0.6	0.7	0.8
Consumption-Growth	0.0	0.2	0.3	0.5	0.6	0.7	0.8
Computer Price-Inflation	-3.4	-4.1	-4.3	-4.4	-4.4	-4.5	-4.5
Total Employment*	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.2
Non-ICT Employment*	0.1	-0.1	-0.4	-0.7	-1.1	-1.9	-2.7
ICT-Employment*	-4.5	3.4	14.4	26.3	39.1	66.7	96.5
High Skilled Emplyment*	-0.1	0.0	0.6	1.3	2.2	4.4	6.7
Low Skilled Employment*	0.2	-0.1	-0.9	-1.8	-2.9	-5.5	-8.5
Wages (Low Skilled)	0.0	0.2	0.4	0.5	0.5	0.6	0.7
Wages (High Skilled)	0.0	0.2	0.4	0.5	0.5	0.6	0.7
Wage Share	0.0	-0.2	-0.6	-1.3	-2.0	-3.6	-5.4
ICT Investment Share (nom.)	-0.1	0.2	0.6	1.0	1.5	2.4	3.4
Investment Share (real)	-0.5	0.0	1.0	2.2	3.4	5.9	8.5
ICT Production Share (nom.)	-0.1	0.1	0.4	0.6	1.0	1.6	2.3
ICT-Import Share	1.0	4.7	9.9	15.3	21.0	33.1	46.2
Real Exchange Rate	8.4	7.6	5.7	3.3	0.7	-5.0	-11.6
Real Interest Rate	0.0	0.3	0.6	1.0	1.2	1.7	2.2

At least within the technological constraints inherent in standard growth models, higher adjustment costs in Europe cannot explain why the boom took place in the US and not so much in Europe, without allowing for substantially higher rates of technical progress.

More Wage Flexibility in Europe

The most striking implication of more wage flexibility in Europe would be an increase in low skilled employment, however at the cost of rising wage dispersion. At least for an elasticity of substitution as used in this paper, real wages of low skilled workers would still grow. Another implication would be a more slowly falling wage share because there would be disproportionately less substitution of low skilled workers. This outcome is consistent with the observation that the wage share has fallen less in the US compared to Europe in the last decade. However, the link from labour market reform to growth is far less strong. Increasing wage flexibility in Europe would not lead to a substantial increase in the growth rate of GDP. It is interesting to notice that the increase in the investment to GDP ratio would actually be smaller, thus labour market reforms would actually slow down the productivity increase and would make growth more labour intensive.

Table 2.6: No relative Wage Rigidity in Europe

	1995	2000	2005	2010	2020	2030	2040
EU:							
TFP-Growth	3.6	3.6	3.6	3.6	3.6	3.6	3.6
GDP_Growth	0.0	0.2	0.3	0.4	0.4	0.5	0.5
Consumption-Growth	0.0	0.1	0.3	0.4	0.5	0.6	0.7
Computer Price-Inflation	-3.5	-4.2	-4.3	-4.3	-4.3	-4.3	-4.4
Total Employment*	0.0	0.1	0.2	0.3	0.4	0.8	1.1
Non-ICT Employment*	0.0	-0.1	-0.1	-0.1	0.0	0.2	0.4
ICT-Employment*	1.1	7.1	10.9	13.7	16.4	22.1	28.3
High Skilled Emplyment*	0.0	0.0	0.1	0.2	0.3	0.6	0.9
Low Skilled Employment*	0.0	0.1	0.1	0.3	0.4	0.7	1.1
Wages (Low Skilled)	0.0	0.1	0.2	0.2	0.2	0.3	0.3
Wages (High Skilled)	0.1	0.2	0.3	0.4	0.4	0.5	0.5
Wage Share	-6.0	-0.2	-0.5	-0.8	-1.2	-2.2	-3.2
ICT Investment Share (nom.)	0.0	0.3	0.5	0.7	0.8	1.2	1.6
Investment Share (real)	-0.4	0.1	0.9	1.7	2.4	4.1	5.8
ICT Production Share (nom.)	0.0	0.2	0.3	0.4	0.4	0.6	0.7
ICT-Import Share	1.0	4.2	8.8	13.7	18.7	29.6	41.4
Real Exchange Rate	8.4	7.7	5.7	2.8	-0.8	-9.7	-20.3
Real Interest Rate	0.1	0.3	0.6	0.8	1.0	1.3	1.6

This result is not inconsistent with the historically high growth rate of capital intensity in Europe, compared to the US. Therefore, somewhat paradoxical, labour market rigidities should encourage firms to invest in unskilled labour saving technologies.

Concluding Remarks

In this paper an attempt has been made to compare the technological and economic developments related to information and communication technologies in the 90s both in the US and Europe. In the first part, comparable information was presented on the likely impact of ICT production and investment on the EU and US economy over the 90s. The empirical evidence suggests that the US has benefited both from ICT production and from investment, while in the case of Europe the effects are so far largely confined to investment. There is also little evidence for substantial spillover effects in the form of higher disembodied technical progress in the rest of the economy due to ICT investment. This does of course not mean that the ICT revolution does not lead to organisational improvements in the corporate sector it only means that these improvements are not extraordinary when compared with previous advances.

The second part of the paper extends the growth accounting exercise by allowing for various macroeconomic feedback mechanisms. Consistency with the growth accounting analysis is preserved by using a conventional neoclassical growth model with constant returns to scale technology and which is disaggregated on the production side into an ICT and a non-ICT sector. By allowing for differences in capital adjustment costs and labour markets between Europe and the US the model allows to look at the importance of technological and structural factors for explaining the growth gap between the US and Europe. Finally the model is also used to see whether the evolution of investment, production and import shares which is taken as given in the growth accounting analysis can be explained by technological and/or economic factors. In this respect the papers finding is that a TFP growth acceleration in Europe that is about 50% (or 1/3 if one takes composition effects into account) of that in the US is most compatible with the observed ICT shares over the last five years. As a consequence of the uneven international distribution of the technology shock, growth accelerates faster in the US because the TFP shock increases productivity instantaneously in the US and therefore shows up earlier in GDP then an acceleration that is mainly fueled mainly via capital formation. There is also an international element that limits growth in Europe initially. Because of higher profit opportunities in the US, there is a capital outflow from Europe to the US (higher interest rates) which compensates the higher US export demand. However in the longer run, as profit opportunities are eroding in the US, the income effect is dominating and is increasing the growth rate in Europe as well.

The paper also explores the often heard view that structural rigidities may have prevented the EU from enjoying similar growth rates than the US. Two structural impediments to growth in the EU are analysed, namely high capital adjustment costs and relative wage rigidity. Though both of them have important implications for welfare in Europe, the paper finds that they cannot explain the growth differential over the last five years. The best explanation seems to be differences in the rate of technical progress in ICT production. Therefore, rather than blaming Eurosclerosis in general one should instead focus more narrowly on determinants of comparative advantage, the US might have in the production of high tech goods.

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Appendix: **The EU-US Model**

There are two countries; The economy in country i (i=1,2)[9] consists of a continuum of households indexed by z on the closed interval [0,1], as well as a corporate sector and a government. The corporate sector is disaggregated into an ICT and a non-ICT producing sector. The ICT sector only produces investment goods, while the non-ICT sector produces consumption and investment goods. We will describe the economy from the perspective of the home country. The goods produced in the two countries are imperfect substitutes. There exists perfect international capital mobility but zero labour mobility. Households in country i derive utility from consumption of domestic and foreign goods, C_t^d and C_t^f respectively. We assume that the utility function $C(C^d, C^f)$ is of the CES type

$$C_{t,z} = \left[\xi C_{t,z}^{d\ \rho} + (1-\xi) C_{t,z}^{f\ \rho}\right]^{1/\rho} \qquad \rho<1, \sigma=1/(1-\rho). \tag{1}$$

where σ denotes the elasticity of substitution between domestic and foreign goods. Households objective is to maximise a time separable intertemporal utility function with constant elasticity of substitution. We follow Blanchard (1985) and assume that each household faces a constant probability of death π each period. As shown for example by Cardia (1991), the household problem can be rewritten in discrete time by weighting the expected utility at time t+j with the probability that the household is alive at t+j, which is $(1+\pi)^{-j}$. Thus the household maximises

$$Max \sum_{j=0}^{\infty} \left[(1+\theta)(1+\pi)\right]^{-j} E_t \frac{C_{t+j,z}^{\ 1-\omega}}{1-\omega} \tag{2}$$

where θ denotes the rate of time preference and ω the inverse of the elasticity of intertemporal substitution. Unlike in conventional neoclassical growth models, there is no leisure term in the utility function. Instead it is assumed that households base their labour supply decision on a concept of permanent income maximisation when negotiating wage contracts with firms where the reservation wage is set by an unemployment insurance system which guarantees unemployment benefits in case of unemployment. Households supply two types of labour, skilled and unskilled. Wage and employment determination will be described more intensively further below. The assumption that households do not value leisure beyond unemployment benefits allows us to disaggregate total consumption easily into the consumption of heterogeneous income groups. Another useful side effect of our specification in the context of open economy models will be the absence of an income effect in the labour supply decision of households. As pointed out by Devereux et al. (1992) and Correia et al. (1995)[10], such models of labour supply are better suited in an open economy context to capture typical cross country correlation patterns. Finally, we assume that because of important fixed costs associated with going to work, households will not choose hours of work but can only supply a fixed number of hours per period which we normalise to one. Total financial wealth $A_{t,z}$ of an individual household consist of three types of assets, government bonds $B_{t,z}$ shares of domestic firms $q_t K_{t,z}$, where q_t is a share

[9] In order to avoid excessive notation the country superscript will only be used when strictly necessary.

[10] These authors arrive at a labour supply decision rule which neglects income effects by assuming a model with home production.

price index of the two business sectors and $K_{t,z}$ are units of real domestic capital owned by the household. Households can also store wealth in the form of internationally traded bonds $F_{t,z}$ issued by private agents in both countries. We assume, without loss of generality, that internationally traded bonds are expressed in units of foreign output. Define e_t as units of domestic goods per unit of foreign goods then the value of assets expressed in units of domestic goods is given by

$$A_{t,z} = q_t K_{t,z} + B_{t,z} + e_t F_{t,z}. \tag{3}$$

The budget constraint of the household is now given by

$$A_{t+1,z} = (1+\pi)\left[A_{t,z} + (r_t B_{t,z} + (r_t * + \Delta e_{t+1})F_{t,z} + (d_t + \Delta q_{t+1})K_{t,z})\right] + Y_{t,z}^h - (C_{t,z}^d + e_t C_{t,z}^f) \tag{4}$$

Households have a contract with an insurance company. As long as they live they receive a rate of return π on their total financial wealth. When they die their total wealth accrues to the insurance company. The variable r_t is the one period return on government bonds in the home country and r_t* is the rate of return on foreign bonds, d_t is the dividend per unit of capital, $C_{t,z}^d$ and $C_{t,z}^f$ is the consumption of domestic and foreign goods. $T_{t,z}$ is a lump sum transfer and $Y_{t,z}^h$ is household income in period t. The level of income depends on their employment and skill status. The high and low skilled households (L_t^h, L_t^l) currently employed receive wage income w_t^h and w_t^l the currently unemployed households receive benefits z_t^h and z_t^l [11]. Households maximise the objective function with respect to consumption of domestic and foreign goods as well as the three types of assets. This gives the following first order conditions

$$E_t p_{t+1}^c C_{t+1,z} = \frac{1+r_t}{1+\theta} p_t^c C_{t,z}, \quad \text{with } p_t^c = \left[\xi + (1-\xi)e_t^{(1-\sigma)}\right]^{1/(1-\sigma)} \tag{5}$$

$$\left(\frac{1-\xi}{\xi}\right)^{\sigma}\left(\frac{C_{t,z}^d}{C_{t,z}^f}\right) = e_t^{\sigma} \tag{6}$$

$$\frac{d_{t,z}}{q_t} + E_t\left[\frac{\Delta q_{t+1}}{q_t}\right] = r_t \tag{7}$$

$$r_t * + E_t\left[\frac{\Delta e_{t+1}}{e_t}\right] = r_t \tag{8}$$

Equation (5) gives the familiar first order condition for total consumption of household z. The term p_t^c defines the relative price between the consumption basket and domestic output. Equation (6) determines how the relative price determines consumption of domestic and foreign goods. The three types of assets are perfect substitutes. This property implies two interest arbitrage relations. Dividends plus capital gains per unit of capital must be equal to the one period return of government bonds (equation (7)) and an interest parity condition holds between domestic and foreign bonds (equation (8)).

The two corporate sectors in each region operate under perfect competition. Non-ICT ($Y_{O,t}$) and ICT output ($Y_{N,t}$) is produced with a constant returns to scale production function. It is assumed that the production

[11] The analysis abstracts from any transition between in and out of the labour force.

function is Cobb Douglas over high skilled labour and a low skilled labour and capital aggregate (G). Capital used in each sector is itself a Cobb Douglas aggregate of ICT and non-ICT capital

$$Y_{s,t} = F\left(G(K_{s,t}, L^{h}_{s,t}), L^{l}_{s,t}\right)\Gamma_{s,t} = G^{1-\alpha}_{s,t} {L^{h}_{s,t}}^{\alpha}\Gamma_{s,t} \quad \text{with } s = O, N. \tag{11}$$

$$G(.) = \left[\mu_{s,l} L_{s,t}^{\frac{\nu-1}{\nu}} + \mu_{s,k}\left({K^{O}_{s,t}}^{(1-c)} {K^{N}_{s,t}}^{c}\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}$$

where Γ_t is an exogenous shock to technology. We allow the share of low skilled workers to differ across sectors. In fact we make the extreme assumption that no low skilled workers are employed in the ICT sector. Capital stock of the two assets (z=O,N) changes according to the rate of fixed capital formation $J^{z}_{s,t}$ and the rate of geometric depreciation

$$K^{z}_{s,t} = J^{z}_{s,t} + (1-\delta_z)K^{z}_{s,t-1}. \tag{12}$$

Total investment expenditures are equal to investment purchases plus the cost of installation. The unit installation costs are assumed to be a linear function of the investment to capital ratio with a parameter ϕ. Total investment expenditure is therefore given by

$$I^{z}_{s,t} = J^{z}_{s,t}\left(1 + \frac{\phi_z}{2}\left(\frac{J^{z}_{s,t}}{K^{z}_{s,t}}\right)\right). \tag{13}$$

The adjustment cost specification captures various different rigidities, such as for example government regulations, organisational adjustment and learning frictions within firms. Investment rigidities can also arise in the form of information, transaction and monitoring costs of financial intermediaries. Carlstroem and Fuerst (1999) have shown that the adjustment cost specification is isomorphic to a model of investment with financing constraints. In order to facilitate aggregation we interpret I^{z}_{t} as the physical requirement of a composite investment good. This composite good consists of domestic and imported brands. In the case of non-ICT goods, these brands are combined using a CES technology which is identical to the CES sub-utility function of consumers. In the case of ICT goods we allow for a different CES aggregator. This is necessary since ICT goods are more homogeneous across countries and therefore both the share of foreign goods as well as the elasticity of substitution between domestic and foreign goods is likely to be larger.

Workers are leaving firms at rate s. In order to recruit new workers the firm has to open up job vacancies O_t and advertise actively. The recruitment costs for each vacancy is v_t and it is assumed that it evolves proportional to the nominal wage rate at rate v_0. It is assumed that firms can fill existing vacancies at rate $q \leq 1$ within the period. Employment thus changes according to the following equation

$$L^{n}_{s,t} = qO^{n}_{s,t} + (1-s)L^{n}_{s,t-1}. \quad \text{With } n = h,l \tag{14}$$

Each sector in country i maximises the net present value of its cash flow

$$V_{s,t} = E_t \sum_{j=0}^{\infty}\prod_{k=0}^{j}(1+r_{t+k})^{-1}\left\{\left[Y_{s,t+j} - w_{s,t+j}L_{s,t+j} - v_{t+j}O_{s,t+j}\right] - I_{s,t+j}\right\} \tag{15}$$

subject to the technology, the adjustment cost, the capital accumulation and the employment adjustment constraint. Define with λ and η the multipliers associated with the constraint on capital and labour respectively. Differentiating the objective function with respect to the different types of capital investment goods, types of labour and vacancies, gives the following system of stochastic Euler equations (subject to the transversality condition)

$$\frac{\partial Y_{s,t+j}}{\partial K^{z}_{s,t+j}} = (r_{t+j} + \delta_z)\lambda^{z}_{s,t+j} - \frac{\phi_z}{2}\left(\frac{J^{z}_{s,t+j}}{K^{z}_{s,t+j}}\right)^2 - E_{t+j}\left[\lambda^{z}_{s,t+j+1} - \lambda^{z}_{s,t+j}\right] \tag{16}$$

$$\left(\phi_z \frac{J^{z}_{s,t+j}}{K^{z}_{s,t+j}} + 1\right)p^{c}_{t} = \lambda^{z}_{s,t+j} \tag{17}$$

$$\left(\frac{1-\xi}{\xi}\right)^{\sigma}\left(\frac{I^{z,d}_{s,t}}{I^{z,f}_{s,t}}\right) = e_t^{\ \sigma} \tag{18}$$

$$\frac{\partial Y_{s,t+j}}{\partial L^{n}_{s,t+1}} = (r_{t+j} + s)\eta^{n}_{s,t+j} + w^{n}_{s,t+j} - E_{t+j}\left[\eta^{n}_{s,t+j+1} - \eta^{n}_{s,t+j}\right] \tag{19}$$

$$\eta^{n}_{s,t+j} = qv_{t+j} \tag{20}$$

Equation (16) is the equation of motion of the marginal shadow value of capital λ^k. Equation (17) is the first order condition for total investment and it implies that the cost of a marginal unit of capital, including both its purchase and adjustment costs, must equal the shadow value of capital λ^k. The cost of capital includes both the pure rental price and adjustment costs. Equation (18) determines the optimal choice of domestic and foreign investment goods as a function of the relative price. Equations (19) and (20) define the law of motion of the shadow value of labour and show that labour demand is a positive function of output and negative function of total labour costs. Because it is costly for firms to fill existing vacancies, total labour costs are the sum of pure wage costs and vacancy costs. With vacancy costs, which is a fixed cost that must be paid when an employee is hired, not only capital but also the existing stock of employees constitutes an asset for the firm. Using the first order conditions of the corporate sector the value of the firm can be expressed as the sum of capital and labour input multiplied with their respective shadow prices

$$V_{s,t} = \lambda^{O}_{s,t}K^{O}_{s,t} + \lambda^{N}_{s,t}K^{N}_{s,t} + \eta^{h}_{s,t}L^{h}_{s,t} + \eta^{l}_{s,t}L^{l}_{s,t} = q_{s,t}K_{s,t}\,. \tag{21}$$

Each incumbent worker increases the market value of the firm by an amount equal to marginal hiring costs. The second equality in the above expression follows from the assumption that all investment is equity financed. This implies that firms finance new investment by issuing new shares at price $q_{s,t}$. Thus the corporate sector firms pay dividends $d_{s,t}K_{s,t}$ according to its financing constraint

$$d_{s,t}K_{s,t} = q_{s,t}\Delta K_{s,t} + (Y_{s,t} - w_{s,t}L_{s,t} - v_{s,t}O_{s,t}) - I_{s,t}\,. \tag{22}$$

Dividends are equal to the cash flow plus new equity issues, *i.e.* firms finance investment via equity. Substituting the financing constraint into the arbitrage condition we get

$$\Delta V_{s,t+1} = r_t V_{s,t} - \left((Y_{s,t} - w_{s,t}L_{s,t} - v_{s,t}O_{s,t}) - I_t\right) \tag{23}$$

This difference equation determines the market value of the corporate sector as the present discounted value of its cash flow. This is what the corporate sector maximises.

Unlike in the goods market we assume imperfect competition in the labour market in both countries. Here we follow closely the search model discussed in Pissarides (1990). The basic incentive for search activities in the labour market by both workers and firms are the profit opportunities in present value terms which are associated with a successful job match for both parties. In the case of workers of skill category n, this is given by the difference between the present value of labour income a worker can earn in the case of a successful job match in the current period ($H^{n,e}$), versus the net present value of labour income in the presence of a failure, i. e. of unemployment in the current period ($H^{n,u}$). Here we observe that the human capital of employed and unemployed workers respectively is given by two arbitrage equations. The return from the human capital of an employed worker consists of three components: the current net wage rate, the expected capital loss from a job separation given by $s\left(H^{n,e}-H^{n,u}\right)$, where s is an exogenous separation rate, and the expected capital gain from an expected change in $H^{n,e}$.

$$(\pi + r_t)H_t^{ne} = w_t^n + s\left(H_t^{n,u} - H_t^{n,e}\right) + E_t\left[\Delta H_{t+1}^{n,e}\right] \tag{24}$$

Corresponding to this equation we can write an arbitrage equation for the human capital of an unemployed household as

$$(\pi + r_t)H_t^{n,u} = z_t^n + p(.)\left(H_t^{n,e} - H_t^{n,u}\right) + E_t\left[\Delta H_{t+1}^{n,u}\right] \tag{25}$$

where $p(.) = O_t^n / U_t^n$ is the probability of finding a job in the specific skill segment, which is given by the ratio between the number of vacancies and the number of unemployed. The return in this case consists of unemployment benefits, the expected capital gain from finding a job with probability $p(.)$, and a capital gain from any expected change of $H^{n,u}$ itself. Since we make the assumption that firms can fill vacancies within one period the probability of finding a job is equal to the ratio between vacancies and the number of unemployed workers. For the firm, the return from a successful job match is given by $\eta_{s,t}^n$

We assume that each firm employs many workers and is large enough to eliminate all uncertainty about the flow of labour. Both parties also know about the profit opportunities of the other players. Wages are determined by an implicit bargain at the individual level, *i.e.* the firm engages in Nash bargains with each individual worker by taking the wage of all other employees as given. Furthermore, the firm knows that a worker within a certain skill group would not accept the job if the wage offered would be below in other firms in both sectors. Also the worker knows that a firm would not sign a contract which is above the wage paid by other firms in both sectors of the economy. Thus a common wage for each skill category is paid across both sectors. In deciding how many jobs to offer, the firm anticipates the wage correctly. Thus wage contracts are set such as to maximise the product

$$\underset{\{w_t\}}{Max}\left(H_t^{n,e} - H_t^{n,u}\right)^{\beta}\left(\eta_t^n\right)^{(1-\beta)} \tag{26}$$

This agreement is based on the relative bargaining position of the two parties. The bargaining strength of workers is characterised by the parameter β ($0 \le \beta \le 1$) which determines the fraction of the total return from a successful job match going to workers. Maximising (26) with respect to w_t yields the familiar sharing rule for the division of the surplus where the fraction of the total surplus from a job match going to the worker depends on his bargaining strength

$$H_t^{n,e} - H_t^{n,u} = \beta\left(H_t^{n,e} - H_t^{n,u} + \eta_t^n\right). \tag{27}$$

Using this sharing rule and the marginal condition for labour, the following wage rule can be derived

$$w_t^n = z_t^n + \frac{\beta}{(1-\beta)}\Big((v_t\big(r + s + p(O_t^n, U_t^n)/q\big) - E_t(v_{t+1} - v_t)\Big). \tag{28}$$

Wages are set as a mark-up over the reservation wage. The mark up is a positive function of labour market tightness which here is expressed as the probability of finding a job within the skilled or unskilled segment of the labour market. It also depends positively on aand adjustment costs for labour. The size of the wage mark-up is a positive function of bargaining strength of workers. It is assumed in our analysis that the reservation wage is a constant fraction of the market wage in both segments of the labour market. Therefore differences between low and skilled wages depend primarily on differences in demand and supply for low and high skilled workers. For the European labour market it is assumed that only wages of high skilled workers are set according to rule (28), while the wage of low skilled workers is indexed to high skilled wages and does not respond to labour market conditions in the low skilled segment.

Equilibrium

The market clearing conditions for the goods market in country 1 and 2 are

$$\begin{aligned} Y_{1t}^O &= C_{1t}^d + C_{2t}^f + I_{1t}^{O,d} + I_{2t}^{O,f} \\ Y_{1t}^N &= I_{1t}^{N,d} + I_{2t}^{N,f} \end{aligned} \tag{33}$$

$$\begin{aligned} Y_{2t}^O &= C_{2t}^d + C_{1t}^f + I_{2t}^{O,d} + I_{1t}^{O,f} \\ Y_{2t}^N &= I_{2t}^{N,d} + I_{1t}^{N,f} \end{aligned} \tag{34}$$

All bonds and equity supplied by the domestic government and the corporate sector are held by domestic households. The market clearing condition for internationally traded bonds is

$$F_{1t} + F_{2t} = 0\,. \tag{35}$$

Output prices of sector O in both countries serve as numéraire. The competitive equilibrium of this economy consists of a sequence of prices ($p_t^I, r_t, r_t{*}, e_t$) and allocations ($C_{it}^{z,}$, $C_{it}^{z,}$, $I_{it}^{z,}$, $I_{it}^{z,}$, K_{it}^z, F_{it}, B_{it}) that satisfy the first order conditions of households and firms, the budget constraints of households, governments and firms and goods and bond market equilibrium conditions. Real wages (w_{it}) are determined by the wage contracting rule (28) and firms set employment optimally according to the first order condition (19-20). The labour market equilibrium can coexist with involuntary unemployment. Furthermore, the evolution of the economy is subject to initial conditions (K_{i0}^z, L_{i0}^n, F_{i0}, B_{i0}). Interest rates, the relative price of ICT goods, wages and the exchange rate also ensure that an intertemporal equilibrium condition holds between national saving and investment in both countries.

We use a procedure for the solution of dynamic non-linear forward looking models developed by Laffargue (1990), Boucekkine (1995) and Juillard (1996). The simulation horizon must, however, be chosen long enough such that the solution is close to the steady state at the final date. We set the simulation horizon to 400 periods. Roeger and In’t Veld (1999) provide a more detailed technical discussion of this solution method as well as some sensitivity analysis in the context of permanent shocks.

Model Calibration

To select parameter values we largely follow standard procedures, *i.e.* we base these values on evidence from growth observations and some microeconomic evidence. In cases where this is not possible parameters are chosen close to those of existing studies. The rate of time preference θ is set equal to 0.03 for the US and slightly lower for Europe. The probability of death π is set to 0.02, which corresponds to a life expectancy of 50 years. Estimates of the elasticity of intertemporal substitution vary widely and the parameter ω is set at an average of the estimates found in the literature. Studies using household survey data (see e.g. Attanasio and Weber (1993), Attanasio and Browning (1995)) tend to find higher estimates than those using aggregate time series data, like Hall (1987). We basically follow Krusell et al (2000) for specifying the technology. In particular we choose their estimated value of 1.67 for the elasticity of substitution between low skilled workers and capital and we assume an elasticity of 1 for high skilled workers. Though estimates are only available for the US, the assumption is made that technology is identical to the US and the EU. The depreciation rate for non-ICT capital is set to 6% and to 30% for ICT capital. These values are taken from Jorgenson and Stiroh (2000). Here again, the assumption is made that depreciation is similar in both countries. The adjustment cost parameter is more difficult to pin down on the basis of information on first moments only. It has, however, been noticed before (see, for example, Mendoza (1991)) that the parameter ϕ has a crucial effect on the volatility of investment. It is therefore set in such a way as to match the relative volatility of investment and GDP in both countries. With respect to the separation rate s we draw on information provided by Layard et al. (1990) from data on gross labour market flows. According to their figures the inflow rate into unemployment fluctuates narrowly around two per cent for the reported European countries. For the US they obtain an estimate of 4% . Our assumption that vacancies can be filled within a quarter is based on studies on vacancy duration. A study by van Ours and Ridder (1992) reports average vacancy durations of 45 days for the Dutch economy. Similar estimates can be found for Germany (see Erdmann (1990)). Blanchard and Diamond (1989) report durations of less than one month for the US. The parameter β referred to as the bargaining strength of workers is set to .5. This implies that all relevant differences between the two parties are captured by the two terms $\left(H_t^{n,e} - H_t^{n,u}\right)$ and η_t^l (see Binmore, Rubinstein and Wolinsky (1986) for a discussion of the symmetry axiom).

The level of unemployment compensation determines the reservation wage. Unfortunately, internationally comparable figures on unemployment compensation are not easy to obtain, since countries do not only differ with respect to the replacement ratio but also with respect to benefit duration and coverage. To cover all these different aspects, Layard et al. (1990) have calculated expenditures on benefits per unemployed person as a per cent of output per worker for major OECD countries for the year 1987. According to these figures the ratio within Europe is highest for Denmark (42%) and lowest for Italy (4%) and no calculations are presented for Portugal and Greece. The European average is slightly below 20%. With a wage share of roughly 50%, unemployment benefits amount to roughly 40% of gross wages. The figures for the US suggests that the US replacement ratio is about half the European level. Given the fact that all other parameters have been chosen, the parameter v_0 can be selected such that the model replicates the steady state unemployment rate in both countries.

We set the price elasticity of imports in both regions equal to one for non-ICT goods. A value in this neighbourhood can often be found in empirical studies on import and export equations. The share of imports in total GDP is set to 10% in both regions, which is the mean value over the period 1975 to 1992 for the US and the extra EU trade. The import share for ICT trade are taken from OECD industrial indicators. The parameter for the price elasticity is set to 2. With this value the model replicates changes in ICT import shares.

Table A-1 : Parameter Values

	Europe	**US**	
Utility Function:			
θ	0.029	0.030	Rate of time preference
σ	1.0	1.0	Import price elasticity
ω	2.0	2.0	Inverse of elasticity of intertemporal substitution
ξ	0.9	0.9	Share of domestic goods
π	0.02	0.02	Probability of death
Technology:			
α	0.4	0.4	Output Elasticity of high skilled
ν	1.67	1.67	Elasticity of substitution for low skilled
δ_O	0.06	0.06	Depreciation rate (non-ICT capital)
δ_I	0.30	0.30	Depreciation rate (ICT capital)
ϕ	15	7	Adjustment cost parameter (investment)
Labour Market:			
s	0.02	0.04	Separation rate
β	0.5	0.5	Bargaining strength of workers
z_0	0.40	0.20	Replacement ratio
v_0	0.45	0.42	Vacancy cost (as share of wages)
Trade			
σ	1.0	1.0	Import Price Elasticity (non-ICT goods)
ς	2.0	2.0	Import Price Elasticity (ICT goods)

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